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Abstract

FRANCE'S NUCLEAR POWER PROGRAMME

by

Mr. J. CABANIUS, Equipment Director at Electricité de France.

Mr. J. HOROWITZ, Atomic Reactors Director at the Commissariat à l'Energie Atomique.

The prospects of development of France's consumption of electricity will widen the deficit of her national energy resources.

Nuclear power stations should enable this deficit to be reduced, provided a certain number of uncertainties prevailing today are resolved.

The first programme, put forward by Messrs. Ailleret and Taranger at the 1955 Geneva Conference aimed at commissioning 850 MWe by 1965 ; the programme was devoted to developing the natural uranium-graphite-gas sequence and reaches its completion with the construction of EDF 3, the world's first unit capable of 500 MWe.

Before changing over from the prototype stage to their duplication, Electricité de France decided, in agreement with the Commissariat à l'Energie Atomique to build EDF 4, wich, while reproducing EDF 3's reactor, together with the refereling equipment, the entire control equipment and various other systems, pioneers an important innovation by incorporating the heat exchangers and fans inside the prestressed concrete pressure-vessel housing the core.

At the same time, studies are being carried on on the same type of reactor enabling possible use of a new annular-shaped fuel element, whose use

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would considerably improve the performance of EDF 5, to be envisaged.

On the heavy water side, the construction of EL 4 at Brennilis jointly by the Commissariat à l'Energie Atomique and Electricité de France is continuing. Design work on a 500 MWe reactor of this type has already started.

As regards pressurized water reactors, the Chooz power station is built jointly by Electricité de France and Belgian Utilities.

Finally, the Commissariat à l'Energie Atomique is continuing the construction of the "Rapsodie" rapid neutron reactor at Cadarache, together with studies on a larger power reactor.

It may thus be seen that the technical and economic knowledge gained on these various types of reactor mean that an equipment program may be contemplated which will endow nuclear power stations with a place of ever-increasing importance, by using the country's resources of natural uranium, and later plutonium, to the best ends.

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Abstract

INTERNATIONAL COLLABORATION FOR THE CONSTRUCTION OF NUCLEAR REACTORS

ACTION OF FRANCE

by MM. RENOU - C. E. A.
GOURE - C. E. A.
LEO - EDF
(Commissariat à l'Energie Atomique, France)

Has international collaboration led to judicious achievements or to over hasty expectations ? At a time when large hydraulic reserves are found to be workable in Eastern and Western North America, when natural gas is about to be commercialised in Northern and Southern Europe, when for social reasons the working of coal mines cannot be slowed down too much, it is preferable to proceed with caution if we wish to go far. This is the attitude in France and we do not wish to raise premature hopes in interested countries.

Past experience shows that international collaboration in our field appears to take three different forms, the effect of which on the scientific and industrial structure of the customer country may be very unequal.

a) The sale of a unit, ready for use, is doubtless the quickest to achieve. It may however be of only limited interest to the buyer if this purchase is a "foreign body", not fully assimilable on the scientific, technical and industrial levels, and becomes more of an anomaly than an acquisition.

b) On the other hand, like many other countries France takes part in original European achievements based on research reactors or prototypes ; their completion and success will open up a new era in the international collaboration for the construction of nuclear reactors (Dragon. Orgel).

In addition an experiment carried out with Belgium is the construction of a Franco-Belgian Centre by industrialists of the two countries on behalf of a group of Belgian and French electricity producers.

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c) It seems therefore that projects carried out in common constitute the real solution to the question, both from the viewpoint of good understanding between two countries and to further progress in the nuclear sciences and techniques.

With neighbouring countries France is engaged in fruitful discussions which could lead to the building of common Centres. Agreements will be necessary for these and the more participants, research organisations, producers of electricity and public or private industries involved, the more complex these agreements will be. The interests of the various partners will have to be taken into account, and it must be so arranged that each one gains in proportion to his own contribution.

A common Centre would evidently be an essential stage in international collaboration . In the long run such an enterprise, in spite of the difficulties involved, is the sign of an epoch where a true pooling of national effort is necessary.

This collaboration would involve an exchange of scientific, technical and economic information on various types of reactors (and, as the case arises the carrying out of research and experiments in common), the choice of the type of reactor to be used in the Centre, the study of convenient sites for construction, the examination of the general lay out of the electrical network in the region considered, the placing of funds, the working out of the preliminary draft and the final plan of the Centre, and the construction, by industrial associations of the two countries on behalf of an electricity production group, also of the two countries, the electricity produced being divided between them ; finally, collaboration can be taken beyond the first project by the setting up of a common research and development programme which could lead to the building of an original type of power reactor.

Such an effort should be situated within the framework of an overall collaboration, extended to all the main fields of nuclear science.

This collaboration may be obtained by way of bilateral agreements such as France has signed with a certain number of countries.

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Abstract

THE USE AND EVOLUTION OF THE CEA RESEARCH REACTORS

by MM. C. CHAUVEZ - Head of the Experimental Reactor Department
F. ROSSILLON - Head of the Reactor Service of the Centre
d'Etudes Nucléaires de Grenoble
(Commissariat à l'Energie Atomique, France)

The authors successively examine the different research reactors in use in the French C. E. A. Nuclear Centres. They trace briefly their histories, describing how they have been used up to the present, and how they have been adapted to changes in programme by means of certain modifications. They also describe the reasons which have led to the elaboration of the project for the new reactor OSIRIS.

ZOE, the oldest reactor in the CEA, has been in service in the Centre de Fontenay-aux-Roses since 1948. It is used mainly for measurements of absorption cross-sections in graphite, and for various short irradiations which do not require high fluxes.

The reactor EL 2, in service since 1952, was used for the first studies on gas cooling. It has also been widely used for the production of radioisotopes and for a large number of experiments in the fields of physics, metallurgy and physical chemistry. The ageing of certain elements of the reactor has led to the decision to close it down in the near future

The reactor EL 3 has been widely used for experiments in physics and in the investigation of fuels. The possibilities of the reactor in fast neutron irradiations will be considerably improved by the adoption of a new type of core (the "snow crystal" structure).

TRITON-I, a 2 MW swimming-pool reactor, is used for the most part for fast neutron and gamma irradiations. The modifications being carried out on it at present should result in an increase in the power of the reactor up to 4 or 5 MW. In a neighbouring compartment is housed TRITON-II which is of the same general structure as TRITON-I, but whose maximum power is 100 kW.

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TRITON-II is used solely for studies on shielding.

MELUSINE, a 2 MW swimming-pool reactor, has been in use in the Centre d'Etudes Nucléaires de Grenoble since 1959.

It has supported a very high programme concerned mainly with solid state physics, fundamental research into refractory fissile materials and special graphites, and the study of the behaviour of organic liquids under irradiation. The equipments of MELUSINE are now being modernized.

SILOE, another swimming-pool reactor, has been operating at 15 MW since the end of 1963. The performances achieved constitute a considerable progress in the field of swimming-pool reactors, since the fluxes obtained with SILOE are in the same order of magnitude than those which needed till now a tank type structure, whose numerous disadvantages in the fitting of experiments are well known. SILOE will be used mostly in the study of structural materials, graphites, refractory fissile materials, and for solid state physics.

The reactor PEGASE, in service in the Cadarache Nuclear Centre since 1963, is intended solely for testing full-scale fuel elements of EDF and EL 4 types. The current programme, for the eight loops of the reactor, covers the elements for the reactors EDF 2 EDF 3 and EL 4. New loops are in the course of being studied for the fuel elements of the EDF 4 and EDF 5 reactors.

The general line of the CEA programmes has shown up the considerable need for fast neutron irradiations. The reactor OSIRIS which is in the course of being constructed will serve to complement the CEA's equipment in this field and at the same time fill the gap which will be left in the near future in the Centre de Saclay by the closing down of EL 2. OSIRIS is a light water reactor whose special structure will allow it to function at 50 MW without the disadvantages usually associated with the presence of a heavy waterproof tank. This reactor, which should be put into service in 1966, is mainly intended for the investigation of structural materials, graphite and refractory fuels ; it will also serve to increase the production of high specific activity isotopes, and to develop activation analysis techniques.

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Abstract

SOME GENERAL REMARKS CONCERNING THE EXPERIMENTAL DEVICES AND MEANS FOR FLUX MEASUREMENTS USED IN THE RESEARCH REACTORS OF THE C. E. A.

by MM. F. ROSSILLON
C. CHAUVEZ

(Commissariat à l'Energie Atomique. France)

First, the authors define the operation and organisation lay-out of the research reactors. This out lay is then used as a basis for an examination of the conception, realisation and exploitation of irradiation devices. They then analyse the different operations carried out in placing an irradiation device in the reactor. They point out that the time necessary for decision of construction, conception, for material provision, for construction, out-of-pile tests and security examination is in general longer than the irradiation time. To minimize this time they advise a closer collaboration between the personel of the experimentation laboratory and the reactor personel for the conception of the design. They think it would be preferable to construct the prototypes in the research centre and leave the fabrication of small series to the industry. The methods used for the in-pile operation of the device are also indicated.

Considering the evolution of the construction technics they mention that the requirements for the irradiation conditions are put higher and higher (reactor stability and homogeneity).

Also described are the performances of the main irradiation devices in operation in research reactor in the C. E. A.

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Abstract

THE FUNCTIONING OF THE REACTORS GE - G3 AT MARCOULE AND EDF 1

by M. BOUSSARD - Chef du Département de Construction des Piles
M. STOLTZ - Chef de la Division Nucléaire du Service de la Production Thermique d'E.D.F.
M. CONTE - Chef du Service des Ensembles Industriels G2-G3
(Commissariat à l'Energie Atomique, France)

After resuming briefly the characteristics of the installations G2-G3 at MARCOULE and EDF 1 at CHINON, the authors review the main aspects of the tests, the starting and the exploitation of these reactors.

Among the various points examined, particular emphasis is given to the devices of original nature such as tubular fuel elements, flattening of the neutron flux by stuffing, behaviour of the reactor tanks and the cooling circuits, the blowers, unloading devices, regulation and functioning of the informations.

This analysis deals equally with the performances obtained and the difficulties and the various incidents experienced during the initial starting period. Among the more interesting results, the progressive increase in the power of the MARCOULE reactors is mentionned, obtained through a better knowledge of the parameters covering the functioning of the reactors such as the distribution of the flux and the temperatures etc ... acquired during the course of the exploitation of the reactor.

The conclusion reached by the authors is that the experience gained on these installations has shown :

- that during an initial period, adjustements became necessary, all of which turned out to be possible.
- that an analysis of their functioning has permitted the progressive movement towards a truly industrial exploitation.

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Abstract

DEVELOPMENTS IN NATURAL URANIUM-GRAPHITE REACTORS

by MM. M. BOURGEOIS - Chef du Département des Etudes de Piles - CEA
M. SAITCEVSKY - Chef du Service d'Etudes Générales Nucléaires EDF

(Commissariat à l'Energie Atomique, France)

The French natural uranium-graphite power-reactor programme has been developing - from EDF 1 to EDF 4 - in the direction of an increase of the unit power of the installations, of the specific and volume powers, and of an improvement in the operational security conditions. The high power of EDF 4 (500 MWe) and the integration of the primary circuit into the reactor vessel, which is itself made of pre-stressed concrete, make it possible to make the most of the annular fuel elements already in use in EDF 1, and to arrive thus at a very satisfactory solution.

The use of an internally cooled fuel element (an annular element) has led to a further step forward : it now becomes possible to increase the pressure of the cooling gas without danger of causing creep in the uranium tube. The use of a pre-stressed concrete vessel makes this pressure increase possible, and the integration of the primary circuit avoids the risk of a rapid depressurization which would be in this case a major danger.

This report deals with the main problems presented by this new type of nuclear power station, and gives the main lives of research and studies now being carried out in France.

- Neutronic and thermal research has made it possible to consider using large size fuel elements (internal diameter = 77 mm, external diameter = 95 mm) while still using natural uranium.

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- The problems connected with the production of these elements and with their in pile behaviour are the subject of a large programme, both out of pile and in power reactors (EDF 2) and test reactors (Pégase).

- The increase in the size of the element leads to a large lattice pitch (35 to 40 cm). This makes it possible to consider having one charging aperture per channel or for a small number of channels, whether the charge machine be inside or outside the pressure vessel.

In conclusion are given the main characteristics of a project for a 500 MWe power station using such a fuel element. In particular this project is compared to EDF 4 in order to show the advantages resulting from such developments in gas-graphite natural metallic uranium reactor systems ; these are : a doubling of the specific and volume powers, and a three-fold reduction in the number of channels.

The research now under way will make it possible to calculate the reduction in capital costs which will result from these important technical advances.

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Abstract

SOME ECONOMIC ASPECTS OF NATURAL URANIUM GRAPHITE GAS REACTOR TYPES PRESENT STATUS AND TRENDS OF COSTS IN FRANCE

by M.M. GAUSSENS - C.E.A.
TANGUY - C.E.A.
LEO - Electricité de France

(Commissariat à l'Energie Atomique, France)

The first part of this report defines the economic advantages of natural uranium fuels, which are as follows : the restricted number and relatively simple fabrication processes of the fuel elements, the low cost per kWh of the finished product and the reasonable capital investments involved in this type of fuel cycle as compared to that of enriched uranium. All these factors combine to reduce the arbitrary nature of cost estimates, which is particularly marked in the case of enriched uranium (due to the complexity of its cycle and the uncertainties of plutonium prices). Finally, the wide availability of yellowcake, as opposed to the present day virtual monopoly of isotope separation, and the low cost of natural uranium stockpiling, offer appreciable guarantees in the way of security of supply and economic and political independance as compared with the use of enriched uranium.

As far as overall capital investments are concerned, it is shown that, although graphite-gas reactor costs are higher than those of light water reactors in certain capacity ranges, the situation becomes far less clear when we start taking into account, in the interest of national independance, the cost of nuclear fuel production equipment in the case of each of these types of reactor. Finally, the marginal cost of the power capacity of a graphite-gas reactor is low and its technological limitations have receded(owing particularly to the use of prestres-

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sed concrete). It is a well known fact that the trend is now towards larger power station units, which means that the rentability of natural uranium graphite reactors as compared to other types of reactors will become more and more pronounced.

The second section aims at presenting a realistic short and medium term view of the fuel, running, and investment costs of French natural uranium graphite gas, reactors.

Finally, the economic goals which this type of reactor can reach in the very near future are given. It is thus shown that considerable reduction in investment costs can be obtained without relying on fuel enrichment, and that this development is accompanied moreover by improvements in the operational safety of the reactor. The economic aspects of the main technical problems entailed by these developments are discussed : loading and unloading machines blowers etc ...

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Abstract

EDF 2, EDF 3 AND EDF 4 NUCLEAR POWER STATIONS

by

Mr. BIENVENU — ELECTRICITE de FRANCE - Deputy Director of No 2 Nuclear Region

Mr. LAMIRAL — ELECTRICITE de FRANCE - Deputy Director of No 1 Nuclear Region

Mr. PASSERIEUX — ELECTRICITE de FRANCE - Head of No 1 Nuclear Region Studies Division

Mr. GAUSSOT — ELECTRICITE de FRANCE - Head of No 2 Nuclear Region Studies Division

Mr. BACHER — COMMISSARIAT à l'ENERGIE ATOMIQUE - Reactor Design Department

In this report, the authors describe the three natural uranium-graphite-CO_2 power stations now being built by Electricité de France.

The authors place particular stress on the evolution of their characteristics and the principal equipment employed.

The electrical output has risen from about 200 MW for EDF 2 to 480 MW for EDF 3 and EDF 4. The electrical power produced per ton of uranium has increased from 910 kW for EDF 2 to 1170 kW for EDF 3 and EDF 4. Simultaneously, the temperatures of the gases and the cans have risen and efficiencies have increased.

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This evolution has been made possible, thanks to the progress achieved in fuel elements and power station equipment. EDF 2's metal pressure-vessel, consisting of a sphere about eighteen metres in diameter rated at 28 bars, has been replaced in subsequent power stations by prestressed concrete structures.

To step up the unit powers of the blowers (from 6 to 15 MW), they are now driven by turbines instead of electric motors.

The fuel loading devices, the heat exchangers and the burst slug detection systems have also developed considerably from one power station to the next.

EDF 4 is Electricité de France's first "integrated" power station, with its heat exchanger located in the prestressed concrete pressure-vessel, beneath the reactor. This new arrangement has called for corresponding new internal layout, and certain equipment had to be adpated. However, the designers have striven to keep the other equipment as similar as possible to that developed for EDF 3, as is the case for the core design, the fuel elements, the loading equipment and the turbo-generator sets.

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Abstract

HEAVY WATER MODERATED GAS-COOLED REACTORS

by MM. B. BAILLY DU BOIS
J. L. BERNARD
R. NAUDET
R. ROCHE

(Commissariat à l'Energie Atomique, France)

France has based its main effort for the production of nuclear energy on natural Uranium Graphite-moderated gas-cooled reactors, and has a long term programme for fast reactors, but this country is also engaged in the development of heavy water moderated gas-cooled reactors which appear to present the best middle term prospects. The economy of these reactors, as in the case of Graphite, arises from the use of natural or very slightly enriched Uranium ; heavy water can take the best advantages of this fuel cycle and moreover offers considerable development potential because of better reactor performances. A prototype plant EL 4 (70 MW) is under construction and is described in detail in another paper. The present one deals with the programme devoted to the development of this reactor type in France.

Reasons for selecting this reactor type are given in the first part : advantages and difficulties are underlined. After reviewing the main technological problems and the Research and Development carried out, results already obtained and points still to be confirmed are reported.

The construction of EL 4 is an important step of this programme : it will be a significant demonstration of reactor performances and will afford many experimentation opportunities. Now the design of large power reactors is

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to be considered. Extension and improvements of the mechanical structures used for EL 4 are under study, as well as alternative concepts.

The paper gives some data for a large reactor in the present state of technology, as a result from optimization studies. Technical improvements, especially in the field of materials could lead to even more interesting performances. Some prospects are mentioned for the long run. Investment costs and fuel cycles are discussed in the last part.

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Abstract

CHARACTERISTICS AND CONSTRUCTION PROBLEMS OF EL 4

by R. CARLE - Ingénieur au D.C.P. - C.E.A.
P. SCHULHOF - Ingénieur au D.C.P. - C.E.A.
P. SEVIN - Ingénieur à la R.E.N. 2 (E.D.F.)

(Commissariat à l'Energie Atomique, France)

EL 4 is the prototype of a new series of reactors moderated with heavy water and cooled by carbon dioxyde. It was studied with a double purpose :

- to realize a sufficiently large and complete reactor for testing the problems of construction and operation of this type of reactors.
- to keep in this installation the possibility of adapting the improvements (new materials, improved fuel elements) studied in the R. and D. program.

The first objective could not be considered without a considerable volume of preliminary work. This work included particularly the construction and testing from 1962 to 1964 of several prototype channels, out of pile, but under the actual temperature and pressure conditions. These tests showed the proper behaviour of the materials under the severe mechanical and chemical conditions of the reactor.

These installations will, furthermore, be available for testing further modifications before adapting them to the reactor. Important tests concerning the safety of the reactor in the avent of an explosion of the CO_2 circuit have also been carried out.

Construction itself began in July 1962 under the double direction of

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the Commissariat à l'Energie Atomique and Electricité de France. The civil engineering work will be finished in 1964. The airtight containment (in which it was considered preferable to house the reactor because of its prototype character) was built in pre-stressed concrete, a method which appeared to be particularly rapid and easy.

The main piece of the reactor is the heavy water tank. This tank is composed of two double end plates equipped with 216 tubes and joined by a steel cylinder. Some difficult welding problems according to the specifications were solved during the construction of these bottoms. A rigorous series of controls by radiographic and ultrasonic methods was adapted to a complicated geometry. The assembly of the reactor unit, and particularly of the array of tubes supplying the 216 channels, was studied in every detail and the connections to be employed were tested. The whole circuit is made in fairly classical materials (slightly alloyed steels) whose behaviour in the carbon dioxyde at 500°C was proved.

The CO_2 and heavy water circuits construction will begin in october 1964.

Aerodynamic tests were carried out for the helico-centrifugal blowers (of unit power 9 MW). The choice of a pressure as high as 60 kg/cm^2 does not seem to induce new problems in connection with leaks on the machine shafts.

Finally, the choice of a type of CO_2 - steam heat exchanger with forced circulation led Electricité de France to test the operation and stability of a prototype exchanger in its test plant. The reactor will be equipped with a depressurizing and desuperheating system which will allow the reactor to operate at 20 p. 100 of its nominal power whether the turbo-alternator is available or not.

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Abstract

PRESENT CONCEPTIONS OF THE C.E.A. CONCERNING THE DEVELOPMENT OF FAST NEUTRON REACTORS

by G. VENDRYES

(Commissariat à l'Energie Atomique, France)

1° - The position of fast neutron reactors in the French nuclear energy program.

In developing a program based on natural uranium, France will have an important stock of plutonium rich in higher isotopes. The existence of this plutonium and of the depleted uranium arising from the same reactors, has, as a logical consequence, the use of both in fast neutron reactors. Justified by this short term interest, the achievement of fast neutron reactors does, moreover, provide for a future necessity.

2° - Description of a fast neutron central power station of 1000 MWe.

We indicate the characteristics of a future fast neutron central power station, plutonium fuelled, and sodium cooled. However uncertain these characteristics may be, they constitue a necessary guide in the orientation of our work.

3° - Studies carried out up to the present time.

We give an outline of those studies, often very preliminary, which have given the characteristics cited above. The principal technical areas taken up are the following :

- Neutronics (critical masses, breeding ratios, enrichments, flattening of the

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neutron flux, coefficients of reactivity, reactivity changes as a function of irradiation).

- Dynamics, control, and safety.
- Fuel
- Technology (design of the core and vessel, of the sodium system, and of the fuel handling mechanisms).

These technical studies are complemented by economic considerations. The choice of the optimum characteristics is related to the existence of power production programs, and, in these programs, to the existence of plutonium producing thermal reactors. It is shown how, in this context, the existence of plutonium should be taken into account, and, in addition which mechanisms relate the economics of this plutonium to the choice of the most important parameters of the breeder reactors.

4° - Prototype reactor.

The interest in an intermediate stage consisting of a reactor of a power level of about 80 MWe is justified. Its essential characteristics are briefly presented.

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Abstract

RAPSODIE

(Commissariat à l'Energie Atomique, France)

Rapsodie, the first fast neutron reactor to be constructed in France by an association formed by Euratom and the CEA, fulfills the following three aims :

- It will serve first of all as an experimental reactor for the investigation of its behaviour under static and dynamic conditions.

- The information obtained from its construction and functioning will serve to develop the technology of future fast neutron industrial reactors.

- Its fast neutron flux will be sufficiently intense for the irradiation tests of fuel elements for subsequent fast neutron reactors.

Since Rapsodie has already been described, we will give only a brief account of it, underlining the particularily interesting points and the recent changes in the programme. We will mention the following points :

- its principle neutron and thermal characteristics
- the fuel and breeding assemblys
- the reactor block and cooling circuits
- the principles and modes of operating on the control and safety of the reactor.

The construction of the reactor was preceeded by the construction of full-scale models of its essential parts, which include notably :

- a complete 10 MW sodium circuit, a prototype of the two circuits which equip the reactor.

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- a model of the reactor block (tank, upper shutter, internal structure of the core and of the cover), furnished with a special sodium circuit in order to be able to carry out tests on endurance and thermal shocks.
- prototypes of various elements of the reactor (mechanism of the control rods, equipment for handling the assemblys, etc ...).
- the hood to be used in the loading and unloading of the assemblys in the reactors was temporarily mounted beside the model of the tank in order to adjust their functioning together under conditions identical with those of the reactor.

Testing began on these various models in 1962, and is continuing. A description of the results of these tests and the information gathered from them will be presented in this report.

A number of interesting studies were carried out on the safety of Rapsodie, and in particular scale models (1/3 and 1/10) were used to estimate the damage caused by the theoretical maximum nuclear accident.

The construction of the reactor was started in the autum of 1961. The industrial architects are the Groupement Atomique Alsacienne Atlantique (G.AAA). A brief outline of the current situation in the construction will be given.

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Abstract

INTEGRATING NUCLEAR POWER INTO FRANCE'S ELECTRICITY NETWORK

by Mr. JANIN - ELECTRICITE de FRANCE - General Economic Studies Division

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Compared to fossile thermal power, nuclear power involves a higher capital cost, at least in its present stage of technical development. Nuclear power stations are therefore only preferable when they can operate for long periods.

Study of the possibilities of developing this new form of energy must be based on the load curve of the network.

Until now, hydro and thermal power have appreciably shared the task of supplying the French network. Allowing for its limited potential development, hydro power is now expanding at a constant rate, whereas consumption is continuing its exponential increase. The proportion to be supplied by fossile-based and nuclear fuel thermal power will therfore rise.

Hydro generating methods will, as far as possible, be more and more directed towards the generation of small amounts of power. Over-equipping of existing power stations will also contribute towards proper operation of thermal and nuclear station, by supplying peak loads.

Since the radio between the maximum and minimum points on the

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load diagram is about 2, the possibility of integrating basic nuclear power naturally involves no problem at present. It has been verified that, even with the highest possible expansion which may reasonably be expected for this power, it will not exceed the zone of maximum use during the next twenty years. It is therefore not the requirements of the load curve that are now hindering rapid development of this new source of power, but rather the uncertainly, altough less felt today, as regards the physical and economical performance of the new power stations.

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Abstract

THE DIRECT CONVERSION OF HEAT INTO ELECTRICITY IN REACTORS

by MM. B. DEVIN
L. KOCH
J. P. DURAND
R. LESUEUR

Service d'Electronique Physique
Centre d'Etudes Nucléaires de Saclay
(Commissariat à l'Energie Atomique, France)

The direct conversion of heat into electricity by thermionic emission in an atomic reactor has been studied with the triple aim of its utilisation : as an energy source for a space device, at the head of a conventional conversion system in power installations, or finally in association with the thermoelectric conversion in very low power installations.

The laboratory experiments were mainly orientated towards the electron extraction of metals and compounds and their behaviour at high temperatures.

Converters furnishing up to 50 amps at 0.4 volts with an efficiency close to 10 p. 100 have been constructed in the laboratory ; the emitters were heated by electron bombardment and were composed of tungsten covered with an uranium carbide deposit or molybdenum covered with cesium.

The main aspects of the coupling between the converter and the reac-

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tor have been covered from the point of view of electronics : the influence of the mismatching of the load on the temperature of the emitter and the influence of thermal flux density on the temperature of the emitter and the stability of the converter.

Converters using uranium carbide as the electron emitter have been tested in reactors. Tests have been made under dynamic conditions in order to determine the dynamic characteristics.

The load matching curves have been constructed and the overall performances of several cells coupled in such a way as to form a reactor rod have been deduced.

This information is fundamental to the design of a control system for a thermionic conversion reactor.

The problems associated with the reliability of thermionic converters connected in series in the same reactor rod have been examined theoretically.

Finally, the absorption isothermals have been drawn at the ambient temperatures for krypton and xenon on activated carbon with the aim of investigating the escape of fission products in a converter.

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Abstract

PRELIMINARY STUDIES ON THE CLOSED CYCLE MAGNETOAERODYNAMIC CONVERTER

This report deals with the work performed at the Saclay Center [1] of "Commissariat à l'Energie Atomique" and at the Fontenay Center [2] of "Electricité de France"

(Commissariat à l'Energie Atomique, France)

Besides the open cycle MHD converters which convert the thermal energy contained in combustion gases a closed cycle converter which can work with any high temperature heat source and specially with nuclear sources is being very carefully studied.

Before proceeding to a practical study of the power station as a whole the performances of the converter itself must be fully investigated. These performances are largely a function of the conductivity of the gas, but this conductivity must not be repaid by a temperature technically unacceptable for the heat exchanger.

In the conversion fluid an ionizable seeding vapour such as caesium or potassium is mixed with a carrier gas, helium or argon. Purely thermal ionization is only efficient above 2 500°K, whereas the electric field obtained by induction in the converter can, under given conditions, increase the electron temperature and produce an ionization rate well above the equilibrium value. This allows the gas to be ionized at moderate temperature. Studies are under way in order to clarify the conditions required to produce extra-thermal ionization in seeded rare gases.

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Measurements have been performed with a 3-phase 500 kVA [2] plasmatron with potassium-seeded argon. The outgoing gas is fed into a channel where the tensor components of conductivity are measured in the presence of a magnetic field. The values found under thermodynamic equilibrium conditions confirm the simple theory. This is not the case when the electrons are heated.

Measurements of the same kind have been made by another method [1] in caesium-seeded helium contained in an isothermal vessel at 1 900°K. There also the equilibrium values are in good agreement, but non-equilibrium ionization seems to be lower than expected.

The effect of electron heating inside the converter in the case of argon-potassium mixture has been considered in a theoretical study [2] . It is shown that the electrode set must be carefully subdivided along the channel, and that electron heating in argon-potassium can be achieved by magnetic fields from 1 to 2 Ts.

Plans are being made to build an important facility [1] which will work on the principle of hot shots. The gas generator will deliver caesium-seeded helium shots at a temperature of 2 100°K. The shot will last 1/10 s and the instantaneous thermal power will reach 1 MW.

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Abstract

ECONOMIC ASPECT OF ELECTRICITY AND INDUSTRIAL HEAT GENERATING REACTORS

by M. GAUSSENS - C.E.A.
Melle DUTHEIL - C.E.A.
M. ALDEBERT - I.N.S.T.N.
MM. CRETTE - G.A.A.A.
PICOU - G.A.A.A.

(Commissariat à l'Energie Atomique, France)

The economic advantage of electricity-generating nuclear stations decreases when their size decreases. However, when a counter-pressure turbine is joined on to a reactor and the residual heat can be properly used, it can be shown that fairly low capacity nuclear equipment may compete with conventional equipment under certain realistic enough conditions. The aim of this paper is to define these special conditions under which nuclear energy can be profitable. They are connected with the location and the general economic environment of the station, the pattern of the electricity and heat demands it must meet, the level of fuel and specific capital costs, nuclear and conventional. These conditions entail certain technical and economic specifications for the reactors used in this way otherwise they are unlikely to be competitive.

In addition, these results are referred to the potential steam and electricity market, which leads us to examine certain uses for the heat generated by double purpose power stations ; for example, to supply combined industrial plants, various types of town heating and for removal of salt from sea water.

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Abstract

SILOE, OSIRIS, AND THE FUTURE PERSPECTIVES OF SWIMMING-POOL REACTORS

by MM. G. DENIELOU
J. CHATOUX
B. LEROUGE

(Commissariat à l'Energie Atomique, France)

SILOE and OSIRIS are two now general purpose research reactors of the "Commissariat à l'Energie Atomique".

SILOE, located within the "Centre d'Etudes Nucléaires" of GRENOBLE is a swimming pool reactor of the same type as MELUSINE and TRITON. It operates at a nominal power of 15 MW thermal and has reached the peak power of 20 MW thermal with two thirds of its cooling system working. The fast flux above 1 MeV, which is maximum at the center of the core at 15 MW thermal is $1,2.10^{14}$. The core, quite open, is downward cooled. Average specific power is 159 kW/l.

OSIRIS is under construction at SACLAY. Designed for 50 MW thermal, this reactor is upward cooled. The fast flux at the center of the core above 1 MeV is calculated to be $2,5.10^{14}$. The average designed specific power is 280 kW/l. A fixed zircalloy gamma shield makes a box round the core.

Future perspectives open to non-pressurised swimming-pool reactors are examined. Ways are suggested for neutronic ; thermal and shielding modifications which make possible further improvements in the performances and economy of these devices.

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Abstract

THE REACTOR PEGASE

by R. DAUTRAY - Direction des Piles Atomiques ; CEA
A. DEVILLE - Département des Piles Expérimentales ; CEA
P. FAUROT - Département des Constructions des Piles ; CEA
J. LACOUR - Département des Etudes de Piles ; CEA
B. LEROUGE - Département des Piles Expérimentales ; CEA
V. RAIEVSKI - CEA during the Pegasus project ; at present Euratom.

(Commissariat à l'Energie Atomique, France)

The reactor Pégase is designed for testing fuel elements for gas-cooled power reactors. Experience has shown that the classical multi-purpose test reactors are not well adapted to these tests. On another side, the introduction of these test elements into the existing power reactors involves numerous problems, which limits their interest.

Pégase, which is designed to satisfy these experimental needs, is composed of a parallelepipediccore of enriched Uranium, moderated and cooled by pressurized water. This core is used as a neutron source for eight autonomous loops, containing the elements to be tested, and situated around the core. The core and the eight loops are immersed in a irradiation pool. The loops are placed on the bottom of the pool so, it is possible to move a loop away from the core, or to remove it from the pool without interfering with the operation of the other loops.

The irradiation conditions are adjusted, moking the synthesis of the following development works.

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- Experimental studies on Peggy, a zero power critical, facilites, mock up of Pégase in operation since 1961 : measurements of neutron flux level, radial and axial fly distributions on the experiments. Effect of burnable poisons and of movements of the control rods ; adjustement of devices (reflectors, screens etc ..) needed for optimum performances.

- Experimental work on two prototypes autonomes loops, heated electrically to the nominal operating power (in operation since 1961) : development of the thermodynamic measurements, thermal balances parameters for control of the operating conditions, natural convection.

- Studies on Pégase operating under power ; thermodynamic measurements on the core circuits on the independant loop circuits ; neutronic measurements, etc ...

The reactor Pégase went critical on the 4th of April 1963 and reached the nominal power of 30 kW on the 28th of May 1963.

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Abstract

PROJECT FOR A HIGH-FLUX EXTRACTED NEUTRON BEAM REACTOR FOR PHYSICISTS

by MM. G. DENIELOU
D. JACROT
L. WEIL
A. LACAZE
P. AGERON
P. PERROUD
DAUTRAY

(Commissariat à l'Energie Atomique, France)

French requirements in neutron beams of different energies extracted from a reactor are briefly described. The well-known importance of cold neutrons (above 4 A°) is emphasized. The main characteristics of a reactor suitable for physicists are outlined : They are :

1° - A flux of about 7.10^{14} thermal neutrons in the heavy water of the reflector

2° - Maximum flexibility obtained by :

- physical separation of the core and the reflector
- independance of the different experiments
- possibility of modifying physical experiments up to - and including - the nature of the used reflector, without any appreciable interruption in the operation of the reactor.
- reduction of fixed shields to a minimum ; ample use of liquid shields (water) and fluid shields (sands).

3° - Technological continuity as far as possible with French research reactors (SILOE, PEGASE, OSIRIS) already existing or under construction.

4° - Safety of operation arising from simplicity of conception.

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5° - Minimised construction costs. Lowering of the operating costs is looked for indirectly in the simplification of the solutions and the reduction of operating staff, rather than directly by reducing the consumption of fuel elements and energy.

The recommended solution can be described as a closed-core non-pressurized swimming-pool reactor, highly under-moderated by the cooling light water.

Surrounding the reactor are a number of "beam tubes-loops" each consisting of :

- a part of the reflector (heavy water in the example described)
- a part of neutron extraction beam tube
- the circuits required for their cooling
- the inlet systems of suitable fluids to the beam tube nose (liquid hydrogen in the example described)
- the necessary outlets for measurement and control system.

The whole "beam tubes loops" is immersed in the water of the metallic self-supporting swimming-pool.

The shielding outside the swimming-pool is composed for the most part by heavy sand in which is the rest of the beam extraction tubes and the experimental equipment which can support doses much higher than the ones which are biologically permissible.

The final part of the communication describes the studies carried out on the realization a liquid hydrogen cold sink, one of the most important experimental devices envisaged.

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Abstract

AERODYNAMIC AND THERMAL STUDIES OF CANS OF GAS COOLED FUEL ELEMENTS

by MM. P. GELIN (CEA - Direction des Piles Atomiques - Département des Etudes de Piles)
J. P. MILLIAT (EDF - Direction des Etudes et Recherches - Centre de Recherche et d'essais de Chatou)

(Commissariat à l'Energie Atomique, France)

Research on clusters was undertaken at the CEA in 1959, while studies on herring-bone cans were developed at the EDF Laboratory at Chatou and the CEA Laboratory at Saclay, at the end of 1959. In 1962, a general study on corrugations was begun at the Saclay Laboratory with a view to improving the clusters, and continued later in both laboratories relative to the internal cooling of annular fuel elements. As these studies progressed, trial facilities were extended while experimental methods have improved constantly. At the present time, both laboratories, working in complete collaboration, have powerful means at their disposal.

Work on the clusters has been concerned chiefly with pressure losses due to the assembly parts, and with the temperature variations around the elements of the cluster. In this way, we have been able to determine satisfactorily the hot points of the can, the deformations of the rods and the conditions of stability of these deformations.

In the case of the herring-bone cans, studies have been directed to the

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evolution of performances as a function of the geometric parameters on the one hand, and to the special aerodynamic and thermal features caused by the fins and by interruptions of cartridge on the other hand. These studies have led to a very thorough knowledge of the cartridges chosen for the reactors EDF 2 and EDF 3, and now, open up very hopeful prospects for future reactors, particularly those fitted with annular elements ; among the alternatives suitable for the inner surface of the annular element can, corrugations and longitudinal fins have been fairly extensively tested over a wide range of Reynolds number.

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Abstract

STUDY OF NEW STRUCTURES ADAPTED TO GAS-GRAPHITE AND GAS-HEAVY-WATER REACTORS

by MM. R. MARTIN et R. ROCHE
(Commissariat à l'Energie Atomique, France)

The experience acquired as a result of the operation of the MARCOULE reactors and of the construction and start-up of the E.D.F. reactors on the one hand, and the conclusions of research and tests carried out out-of-pile on the other hand, lead to a considerable change in the general design of reactors of the gas-graphite type.

The main modifications envisaged are analysed in the paper. The adoption of an annular fuel element and of a down-current cooling will make it possible to increase considerably the specific power and the power output of each channel ; as a result there will be a considerable reduction in the number of the channels and a corresponding increase in the size of the unit cell. The graphite stack will have to be adapted to there new conditions. For security reasons, the use of prestressed concrete for the construction of the reactor vessel is becoming more widespread ; they could lead to the exchangers and the fuel-handling apparatus becoming integrated inside the vessel (the so-called "attic" device). A full-size model of this attic has been built at Saclay with the participation of EURATOM ; the operational results obtained are presented as well as a new original design for the control rods.

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As for as the gas-heavy-water system is concerned, the research is carried out on two points of design ; the first, which retains the use of horizontal pressure tubes, takes into account the experience acquired during the construction of the EL 4 reactor of which it will constitute an extrapolation ; the second, arising from the research carried out on the gas-graphite system, will use a pre-stressed concrete vessel for holding the pressure, the moderator being almost at the same pressure as the cooling fluid and the fuel being placed in vertical channels.

The relative merits of these two variants are analysed in the present paper.

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Abstract

THE PRESTRESSED CONCRETE PRESSURE-VESSELS OF THE FRENCH NATURAL URANIUM-GRAPHITE-CARBON DIOXIDE GAS SEQUENCE REACTORS

by

Mr. Georges LAMIRAL — Electricité de France : Deputy Director of No. 1 Nuclear Region.

Mr. Louis LAURENT — Electricité de France : Head of Reactor Division of No. 1 Nuclear Region.

Mr. BONNELLE — Electricité de France : Head of Civil Engineering Division of No. 2 Nuclear Region.

Mr. BEAUJOINT — Electricité de France : Head of Civil Engineering Division of the Nuclear Technical and Mechanical Engineering Department of the Chatou Research and Testing Centre.

Mr. FAUROT — Commissariat à l'Energie Atomique : Reactor Construction Division, Head of Engineering Section.

The first prestressed concrete pressur-vessels for nuclear reactors were built at Marcoule between 1956 and 1960 by the French Atomic Energy Authority (C.E.A.).

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After recalling the features of these pressure-vessels, the report defines the basic components and describes the pressure-vessels of the reactors of EDF 3 and EDF 4 power stations, built respectively at Chinon and at St-Laurent-des-Eaux by Electricité de France.

The pressure-vessel of EDF 3 power station, designed for an operating pressure of 30 atmospheres, has approximately the shape of a parallélépipède with a square base with sides 25 mètres long, and is 32 mètres high ; its effective capacity is bounded by a cylinder 19 mètres in diameter and 21 mètres high.

The pressure-vessel of EDF 4 power station, which houses the reactor core and the heat exchangers, is designed for an operating pressure of 29 atmospheres ; its effective capacity is bounded by a cylinder 19 mètres in diameter and about 37 mètres high.

The design of these structures sets many problems, wich can only be overcome after trials on scale models.

Since the high temperatures reached by the carton dioxide gas are today considered incompatible with prestressed concrete, the concrete has to be insulated from the gas and cooled ; many tests have been carried out and new solutions found for these problems.

The inclusion of the primary circuit within the reactor pressure-vessel meant such huge dimensions that prestressed concrete was the only feasible solution ; any development of natural uranium-graphite-carbon dioxide gas type reactors are therefore tied to the development of this technique ; problems concerning the use of prestressed concrete for reactor pressure-vessels are at present being subjected to various studies in France.

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Abstract

TECHNOLOGICAL STUDY OF ORGANIC COOLING FLUIDS

by P. LEVEQUE - C.E.A.
F. FRANZETTI - C.E.A.
P. MAS - C.E.A.
M. MASSON - C.E.A.
J.R. PUIG - C.E.A.
A. HOULLIER - PROGIL Society
R. CHAUDET - PROGIL Society
D. ROSIER - PROGIL Society
P. GIULIANI - I.F.P.
G. LELEU - I.F.P.

(Commissariat à l'Energie Atomique, France)

Under contract to Euratom (MM. VAN der VENNE and HANNAERT), the C.E.A. and the Progil Society have collaborated on a technological study of the terphenyls. The results obtained from the radiolysis and pyrolysis of the product OM2 (70 p.100 m-terphenyl, 25 p.100 o-terphenyl, 5 p.100 p-terphenyl) are reported. Using two pile loops at temperatures up to 450°C, a phenomena of accelerated pyrolysis on the radiolysed material has been demonstrated.
Some by - products of the petroleum industry have also been studied, with a view to finding substitutes for terphenyl.

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Abstract

FUEL LOADING AND UNLOADING DEVICES FOR THE FRENCH NATURAL URANIUM - GRAPHITE - GAS SEQUENCE REACTORS

by Mr. Boris SAITCEVSKY : ELECTRICITE DE FRANCE : Head of General Nuclear Studies Division

Mr. Denis GAUSSOT : ELECTRICITE DE FRANCE : Head of No 2 Nuclear Region Studies Division

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The refereling system is one of the vital parts of a natural uranium-graphite-gas sequence nuclear power plant.

From the costs standpoint, it involves 8 to 10 % of total capital expenditure, at the moment. From the technical standpoint, the question is complex, both as regards the tasks the equipment must fulfil and the high safety requirements.

In the first section of the paper, the various fundamental aspects of operation and safety are reviewed, enabling principles universally applicable to be brought out.

The authors then go on to analyse factors governing the basic choice and conclude by emphasising the value of actual operation so as to accumulate long operational experience.

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They then give a brief description of the equipment for EDF 2, EDF 3 and EDF 4 and show how the above principles have been applied to two solutions differing very widely technically :

- at EDF 2, several machines, each specialising in a given task ; preparing the standpipes, auxiliary operations, charging and discharging of the fuel elements into and from the reactor, and maintenance.
- at EDF 3 and EDF 4, a single machine carrying out all these tasks.

In both cases, the equipment is very heavy, owing to the very stringent safety standards adopted.

The report ends with a brief glimpse into cost factors and design and testing methods employed to develop these complex units, in particular, the equipment is tested under nominal pressure and temperature conditions before being sent on site at the Saint-Denis testing station. In addition, beakdown of the cost of the units brings out the relative importance of the design and testing item (about 35 %).

In their conclusions, the authors state that solutions found are very complex, but may be vastly improved upon.

The results of initial pressure and temperature tests justify consideration that the equipment will give every satisfaction, like that for G2 and G3, which were the world's first loading and unloading machines to operate under load.

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Abstract

SOME FUNDAMENTAL ASPECTS OF BOILING IN NUCLEAR REACTORS

by H. MONDIN - C.E.N. de GRENOBLE
J. VILLENEUVE - C.E.N. de GRENOBLE
R. SEMERIA - C.E.N. de GRENOBLE
P. LAVIGNE - C.E.N. de GRENOBLE
S. FABREGA - C.E.N. de GRENOBLE
Ph. VERNIER - C.E.N. de GRENOBLE

(Commissariat à l'Energie Atomique, France)

The main results obtained at Grenoble during the last four years in the field of boiling mechanisms and related phenomena in nuclear reactors are reported.

1. OBSERVATION OF BOILING.

By the use of photography and ultrafast cinematography (8000 frames per second maximum), boiling in a vessel or a tube was observed up to 140 kg/cm^2.

The populations of bubble-generating seeds (sites) were counted, and a correlation established giving their number per unit of surface area as a function of the thermal flux and the pressure.

The diameter of the bubbles breaking of from the wall was studied up to 140 kg/cm^2 : three types of bubble have been shown to exist :

- those in equilibrium, their diameter following the formula of Fritz and Ende.
- bubbles founed by boiling, the diameters of which decrease rapidly with the pressure (1/100 mm to 100 kg/cm^2).
- the coalescences which appear in saturated liquid above 15 W/cm^2, their proportion being independant of the pressure.

Translation provided by courtesy of the submitting Government

Strioscopic observations were made of the movements of the thermal film associated with the generation of the seeds, at the initiation and condensation of the bubbles ; the mechanisms responsable for the highly efficient heat transfer could thus be defined.

2. PRESSURE LOSSES IN TWO-PHASE FLOW.

A physical model of the continuous variation of the free space content in a boiling channel has been proposed by means of which the pressure losses can be calculated without invoking a break in the coefficient of friction when free boiling begins. Agreement between theory and experiment is satisfactory.

The various forms which total pressure loss in a boiling tube may present as a function of flowrate have been studied. Special features are observed at very low and very high speeds.

3. BURN-OUT.

Under steady operating conditions, it is shown that in a uniformly heated channel the burn-out flux as a function of output rate is generally independant of the length.

When burn-out is a result of output oscillation, the conditions of burn-out are compared with those obtained under steady conditions.

The burn-out flux following uniform "stopped" heating has been studied in a channel containing still water. The flux shows a maximum as a function of unsaturation. The influence of the geometry and the nature of the metal was investigated.

4. OUTPUT OSCILLATIONS.

Using a low pressure (8 atm) loop, the influence of various parameters on the periods of output oscillations in a boiling channel on the thresholds at which they appear, was studied.

Some new aspects of this complex phenomena were observed and are reported.

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Abstract

EVOLUTION OF THE URANIUM INDUSTRY IN FRANCE

(Commissariat à l'Energie Atomique, France)

The main feature in the development of the French uranium industry during the last few years is the completion of the programme, abready started in 1958, for the equipment of mining units and treatment plants.

It was thus possible by 1961, to reach a production capacity of about 2000 T of metal contained in concentrates, and about 1800 T of metal of nuclear purity.

The prospection and research carried on in France by the Commissariat and by private Industry have brought about not only a satisfactory renewal of the reserves under exploitation but also the development of two new uranium-producing regions : one of the usual type in France, in the crystalline formations to the South-East of the Massif Central, the other in the Permian sedimentary formations in the department of l'Hérault.

Ore extraction is essentially taken care of by the Commissariat à l'Energie Atomique in the three mining districts Vendée, Limousin and Forez, private industry having been unable to form any large production unit under the conditions prevailing in recent years.

Physical methods of concentration have been gradually abandoned, with the exception of a continuous radiometric sorting at the Bessines plant and the gravimetric concentration of uranothorianite ores at Madagascar.

[1] Translation provided by courtesy of the submitting Government

Uraniferous concentrates are produced in two forms :

-on the one hand two chemical plants run by a combined Commissariat-private industry firm, the Société Industrielle des Minerais de l'Ouest, produce magnesium uranates by a conventional process, in the Vendée and at la Crouzille ;

- on the other hand two Commissariat plants, one managed by the same Society in the Forez, the other run directly by the Commissariat at Gueugnon in the Grury mining district, at present inactive, produce uranyl nitrate : the former from ore extracted in the Forez region, the latter from magnesium uranate preconcentrates imported from Gabon.

Two Commissariat plants convert the concentrates into a product of nuclear purity :

- one at le Bouchet, run by the C. E. A., which also deals with development studies,

- the other at Malvesi, managed by a Commissariat-private industry combine, the Société de Raffinage de l'Uranium.

This latter has a production capacity about double that of le Bouchet and uses the same manufacturing processes.

The bulk of the uranium metal is still produced by calcium reduction, but the le Bouchet plant is already equiped for magnesium reduction and is using this process.

Uranium fluoride is obtained by a technique peculiar to the French process, in combined vertical furnaces giving a direct transformation of trioxide (UO_3) to fluoride with a very low oxygen content ; particularly advantageous production yields can thus be obtained. The equipment of the Malvesi plant will be modernised in the near future to make use of this process.

The plant at le Bouchet also contains equipment for the treatment of uranothorianite concentrates imported from Madagascar. The original process, based on solvent purification and oxalic separation, has been replaced by a more modern method using selective dissolution, which enables pure nitrates to be produced under excellent conditions.